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HIGHLIGHTS IN SPACE TECHNOLOGY AND APPLICATIONS 1991

Report submitted by the International Astronautical Federation

Note by the Secretariat

Annexed herewith is a report on highlights in space technology and applications for 1991 submitted by the International Astronautical Federation (IAF) in accordance with the request of the Scientific and Technical Subcommittee for the submission of annual reports by IAF on scientific and technological developments in the exploration and peaceful uses of outer space.

The report was prepared by Dr. Jerry Grey, former President of IAF, for Dr. Karl Doetsch and Dr. Lubos Perek, Co-Chairman of the International Programme Committee for the 42nd IAF Congress, and was approved by Dr. Alvaro Azcarraga, the current President of IAF. The report is being circulated, as received, only in the language of its submission (English).

Annex

HIGHLIGHTS IN SPACE TECHNOLOGY AND APPLICATIONS 1991

Prepared by the

INTERNATIONAL ASTRONAUTICAL FEDERATION (IAF)

for the

Scientific and Technical Subcommittee
Committee on the Peaceful Uses of Outer Space
UNITED NATIONS

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I. SUMMARY

The most significant developments affecting space technology and applications in 1991 were the ever-increasing budget pressures on national space programs, the broadening trend toward commercializing all space activities, the growing emphasis on environmental research and monitoring from space, the continuing expansion of mobile satellite communications applications, and increasing pressures to use smaller spacecraft.

The most profound changes occurred as a result of the political reorganization of the Soviet Union and the Eastern European nations. Although some results are already apparent, such as the surge in marketing of space products and services by the Soviet nations, the longer-term impacts of these changes on both current and future Soviet and Eastern European space activities have yet to evolve.

Important changes in the U.S. were signaled by the far-reaching December 1990 recommendations of the Committee on the Future of the U.S. Space Program and the release by President Bush in September 1991 of a new U.S. space transportation policy. Responding to budgetary pressures, the U.S. Congress mandated a major rescoping of Space Station Freedom, a recasting of the Earth Observing System for environmental research and monitoring, indefinite postponement of the Space Exploration Initiative despite the strong recommendations of a prestigious Synthesis Group report, and cutbacks in the early phases of new launch system development.

Similar financial pressures in Germany, Italy, France, the United Kingdom, and all member nations of the European Space Agency have necessitated retrenching in many areas of space development, most notably in the Columbus space station program, the Hermes spaceplane, and other large projects.

The most encouraging advances appeared in the proliferation of new commercial organizations and consortia seeking to broaden space-related services in all market areas, particularly in communications and navigation. The demonstrated value of space capabilities during the Desert Storm operations in Kuwait and Iraq revealed many potential new options for commercial and civil applications, some of which have already appeared on the world market.

Another encouraging note is the success of current space exploration missions, which are returning exciting new data on the Solar System and the Universe at an unprecedented rate, despite mechanical difficulties with both onboard systems and launch vehicles. The "New Golden Age" of scientific spacecraft which began last year appears to be well established and thriving.

II. SPACE TRANSPORTATION

A. Current Launch Activities

The USSR conducted 75 launches in 1990, one more than in 1989, continuing the lower launch rate that stems from improvements in Soviet spacecraft lifetime and capability.

Buran-2 underwent tests on the launch pad during the summer in preparation for the next launch of the winged shuttle, currently planned for late 1992. The Molniya Scientific and Industrial Enterprise has built 5 shuttles. One more (in addition to Buran-2) will be outfitted for space flight, one will be used for ground training, and one will be offered for sale. Buran-1, which flew successfully in November 1988, was primarily a test vehicle and is no longer considered flightworthy.

On 30 August an SL-19 Zenit launcher exploded shortly after launch from the Baikonur Cosmodrome. The failure was not caused by the RD-170 engine, which had been responsible for the previous SL-16 loss in October 1990 that also destroyed the launch pad at Baikonur.

General Dynamics received the first commercial launch operator's license from the U.S. Department of Transportation on 22 February. The license covers Atlas launch operations from Cape Canaveral for the next two years.

The first launch of a Titan-4 from the U.S. Western Test Range (WTR) was conducted successfully on 8 March, following three previous Titan-4 launches from the Eastern Test Range (ETR) at Cape Canaveral. Unlike ETR, polar-orbit launches can be made from the WTR. Titan-4 can carry up to 15,000 kg to a 160-km polar orbit. The U.S. Air Force also announced in July its intent to reactivate a WTR launch pad for Atlas 2 vehicles, which makes possible the launch of medium-size polar-orbit satellites such as those now contemplated for NASA's Earth Observing System (see below).

In June Intelsat contracted with General Dynamics to increase the payload capability of its Atlas 2AS launcher by 121 kg to provide extra on-board propellant for the Intelsat 7 satellites, extending their lifetimes to 16 years. Two Intelsat 7s are scheduled for launch in 1995.

B. Development Activity

The U.S. initiated preliminary studies of a new National Launch System (NLS) to be developed jointly by NASA and the U.S. Air Force. It will consist of a family of launch vehicles derived from the Air Force Advanced Launch System and NASA's Space Shuttle, using many common elements; e.g., a 260-kg-thrust hydrogen-oxygen engine, avionics, automated ground-servicing systems, etc. Payloads being considered for the various

configurations, some of which employ solid-propellant boosters, range from about 9,000 kg to over 110,000 kg to low Earth orbit. The NLS is a major element in the new U.S. space transportation policy, announced 24 July, which also rules out the purchase of new Shuttle orbiters after Endeavour. The policy calls for a 10-year launch technology plan to be developed by NASA, the Department of Defense, and the Department of Energy, and also strongly encourages the growth of commercial launch operations.

Conceptual designs for a new U.S. Personnel Launch System (PLS) are being developed at NASA's Langley Research Center. One preliminary version designated HL-20, based on U.S. and Soviet lifting-body research, would carry two pilots and 8 passengers to and from Space Station Freedom using Titan-4 and, eventually, NLS-type launchers.

The U.S. Strategic Defense Initiative Organization awarded a contract in August to McDonnell Douglas for subscale demonstration of a fully recoverable all-rocket single-stage-to-orbit launch concept whose design focus is operational simplicity and quick turnaround. Conceptual designs feature a hydrogen-oxygen segmented plug-nozzle engine driving a conical vehicle with a gross mass of about 400,000 kg and a payload to low Earth orbit of 8,000 kg. Subscale demonstration is scheduled for 1993, using Pratt & Whitney RL-10 A-4 engines modified to ignite at sea level and to incorporate throttling for hovering flight.

Other U.S. vehicles in various stages of development include General Dynamics' Atlas 2AS, which differs from all previous Atlas vehicles in that it uses small solid-propellant boosters to loft 3,600-kg payloads into geosynchronous transfer orbit.

In September the Ukrainian Yuznoye Design Office announced a new small launch vehicle using refitted SS-24 missile launchers deployed from An-124 aircraft. The "Space Clipper" can carry 500-kg payloads into 600-km orbits.

European Space Agency development continued on Ariane-5, which will begin to succeed Ariane-4 in 1995. It can launch over 6,800 kg into geosynchronous transfer orbit, compared with Ariane 44L's 4,200-kg payload capability. Many major elements of the Ariane-5 launch facility at Kourou, French Guiana are complete, and component testing (of the Ariane-5 solid-propellant booster) began there late in 1991.

ESA created a unified European program to coordinate several national programs on post-Ariane launch concepts that utilize hypersonic vehicles. The Future European Space Transportation Investigation Program (FESTIP) is planned to begin in 1993. Its goals are to narrow the various hypersonic-vehicle concepts to a single design and to develop technologies that can be used for other applications.

On April 10 Italy's Alenia signed an agreement with Deutsche Aerospace to conduct advanced materials work for the Saenger

hypersonic aerospace plane program. Sweden and Norway had signed previous agreements to participate in Saenger research. Saenger is a two-stage launcher, using an airbreathing first-stage vehicle up to Mach 6.8 and then a second rocket stage to carry a crew of three and 3,000 kg of cargo to low Earth orbit.

Development of Japan's H-2 launch vehicle, designed to carry 2,000-kg payloads to geostationary orbit, is now paced by LE-7 first-stage engine testing (see below), which may delay the vehicle's first launch until 1994. However, in October Japan's launch-service marketing company, Rocket Systems, submitted a bid to launch Inmarsat 3 satellites aboard H-2 rockets, beginning in November 1994. Meanwhile the National Space Development Agency (NASDA) plans to cooperate with the Institute of Space and Astronautical Science (ISAS) to develop a new launcher for 800-kg satellites using components of NASDA's H-2 and ISAS's M-3S2. A major role for the new vehicle would be in testing the HOPE orbiting space plane. On 16 September Japan launched TR-1A (Tagesaki-1), whose two-stage solid-propellant launcher is similar to the H-2's boosters.

C. Other Transportation Services

British Aerospace Australia, Auspace Ltd, and Hawker de Havilland initiated plans in June to work with the Australian government to reopen the Woomera launch range in southern Australia, which was last used for rocket tests in the 1970s. The range offers good access to the polar orbits used by remote-sensing satellites. In the U.S., Alaska Aerospace Development Corporation was created in July to promote commercial use of the sounding-rocket Poker Flat Research Range launch site.

Ingosstrakh Ltd. Insurance Company became the first Soviet organization offering to provide insurance for both launch and in-orbit failures. Its first policy, issued in September, covered the launch of a Gorizont communications satellite aboard a Proton launch vehicle.

III. UNMANNED EARTH ORBITAL ACTIVITIES

A. Telecommunications

(1) General-Purpose Systems

(a) Europe

On 21 December 1990 the Turkish postal services administration contracted with a team led by France's Aerospatiale to build two Turksat satellites, each carrying 16 Ku-band transponders. The team, which includes France's Alcatel Espace and Germany's MBB, will also provide ground stations and technical assistance. First launch, by Arianespace, is planned for 1993.

An Ariane 44L vehicle successfully launched two European communications satellites on 15 January. Eutelsat 2F2 is the second (of 6) in the Eutelsat-2 series. It carries 16 transponders for television, radio, and business-communication traffic. Italsat 1, built by Selenia Spazio, is Italy's first national communications satellite. It has 9 transponders for use in advanced telecommunications and improved telephone service, and incorporates onboard switching able to redirect up to 12,000 telephone calls.

Italy also announced a new program for two Primosat spacecraft, financed privately by the Intermercato Group of Lucca, Italy, which will market services in Europe with emphasis on Eastern Europe. Each of the small Primosats will weigh about 940 kg and carry eight active transponders plus two spares. Both launches, by Arianespace, are planned for 1993.

Luxembourg's Astra 1B satellite, with 16 transponders, was launched successfully by an Ariane 44LP on 2 March, along with an ESA Meteosat. The spacecraft provides television service to Western Europe.

A newly funded ESA program includes the experimental ARTEMIS satellite and a data relay satellite system. ARTEMIS will carry three advanced payloads to evaluate optical interorbit links, multibeam broadcast, and S-band multiple access. Being built by a consortium led by Selenia Spazio, it is to be launched in 1994.

The experimental Olympus communications satellite, launched in July 1989, began suffering a loss of power on 28 January when one of its solar panels stopped tracking the Sun. Subsequently, on 29 May, the spacecraft tumbled out of control and began drifting eastward out of range of its tracking station at Fucino, Italy. An unprecedented recovery operation was set up by ESA, which was successful in thawing the satellite's frozen fuel without damaging its plumbing, restoring power from its frozen batteries, reestablishing control (the first thruster firings occured on 26 July), and bringing Olympus back to its proper longitude by mid-August. The spacecraft is now once again fully operational.

(b) Asia

A novel aspect of the launch contract negotiations for the 1200-1300-kg Palapa B4 satellite, scheduled for launch late in 1992, was introduced when Indonesia requested all launch bidders to accept raw materials, mostly oil, for their services instead of cash. All three bidders, Chinese, American, and European, agreed to do so. The four previous Palapas were launched aboard U.S. Delta rockets.

Satellite Japan Corporation of Tokyo entered the commercial domestic communications market this year, joining two other

Japanese companies, Space Communications Corporation and Japanese Communications Satellite Corporation (JCSAT), both also of Tokyo. The new company expects to launch two satellites in 1994. Nippon Telephone and Telegraph Corporation (NTT) requested commercial bids in June for two more domestic communications satellites, called N-STAR, to be launched in April 1995.

Toshiba became the first Japanese firm to bid on systems integration and the bus for a commercial satellite program, offering in May to provide these services for two NTT spacecraft each weighing up to 1800 kg and carrying 11 Ka-band, 8 Ku-band, 6 C-band, and 1 S-band transponders. Toshiba based its bid on experience with Japan's ETS-6 spacecraft to be launched in 1993.

On 18 April NHK's BS-3H direct-broadcast satellite was destroyed when one of the two Centaur engines on its Atlas/Centaur launcher failed to ignite. The failure was later traced to debris in the Centaur propellant pump. It was the first Centaur engine failure in over 140 flights. A replacement satellite, BS-3b, was launched successfully by an H-1 rocket from NASDA's Tanegashima Space Center on 25 August. The 550-kg spacecraft has three 120W broadcast transponders and one spare. It went into operation in geostationary orbit at 110 degrees east longitude in November.

The December 1990 in-orbit failure of NHK's Superbird A was traced to improper operation of the spacecraft's attitude control thruster valves, which allowed all the thrusters' oxidizer to leak away. Superbird E (Superbird A's replacement) is scheduled for launch by Arianespace in January 1992; the originally intended replacement, Superbird B, was lost when its Ariane launcher failed in February 1990.

Nippon Hoso Kyokai (NHK), Japan's public broadcasting system, initiated high-definition television (HDTV) broadcasting eight hours daily on one channel from the BS-3b satellite, launched on 25 August (see above). The HDTV broadcasts will supplement NHK's present direct-broadcast television, which now reaches over 4 million households in Japan, with 10 million expected by 1995. JCSAT also began tests this year of digital radio broadcasting, using its Hughes JCSAT-1 spacecraft. It is the first system to employ both direct radio broadcast to customers and digitized radio signal transmission, which is equal in quality to compact discs.

In April Japan announced a new experimental Communications Broadcasting Technology Satellite program to test new techniques. The 1800-kg spacecraft will be launched in 1997 aboard an H-2 rocket, and will carry transponders to relay data from other spacecraft, including space stations; to transmit Ka-band radio and television programs (including HDTV) to small receiving antennas; and to service mobile receivers with Ka-band voice, data, and television and with millimeter-wave communications.

India's INSAT-2A completed final integrated tests prior to

its launch by Arianespace, currently scheduled for March 1992. The second-generation multipurpose satellite weighs 1950 kg and carries 18 C-band transponders, 2 high-power S-band transponders, a Very High Resolution Radiometer for meteorological imaging from the geostationary orbit, and a search-and-rescue payload.

Korea Telecom initiated a two-satellite program to provide domestic telecommunications and direct broadcasting services. The 650-kg satellites are planned for launch in 1995, and will each carry 15 transponders.

Thailand's Shinawatra Computer Company, acting for the Ministry of Transport and Communications, agreed on 10 June to contract with Hughes Space and Communications Group of the U.S. for construction of two lightweight satellites based on the Hughes HS-376 bus. Each satellite will weigh only 400 kg excluding propellant, and will carry 10 C-band and 2 Ku-band transponders. First launch is planned for 1993.

(c) United States

Alascom's Aurora 2 satellite, launched aboard a U.S. Delta on 29 May, replaced Aurora 1. The new satellite, which carries over 12 million telephone calls daily, is equipped with 24 C-band transponders.

The first U.S. license for an audio broadcast satellite was issued on 21 June by the Federal Communications Commission to Worldspace Corporation, which plans to launch its experimental satellite in 1993 on a Chinese rocket. The satellite will be used by Worldspace's subsidiary Afrispace to serve Africa and southwestern Asia.

The fifth Tracking and Data Relay Satellite (TDRS-5) was launched by the crew of Space Shuttle Atlantis on 3 August, and was subsequently moved to its operational position over the Pacific Ocean. Atlantis landed at the Kennedy Space Center's runway in Florida for the first time since 1985.

On 8 September NASA's Office of Commercial Programs selected two Centers for Commercial Development of Space (CCDS) specializing in satellite communications. One of the tasks of the new centers, at the University of Maryland and Florida Atlantic University, will be to garner industry support to develop services and equipment stemming from NASA's Advanced Communications Technology Satellite (ACTS), scheduled for launch in April 1993.

(d) Soviet Union

On 10 April the Soviet Union announced plans to deploy a new series of television broadcast satellites, called Gals, to supplement its present fleet of Ekran spacecraft. Each of the five Gals satellites will carry 3 Ku-band transponders. Two will be located at 44 degrees East longitude; three at 23 degrees

East. The new system will be designed for three different types of receiving antenna: one 2.5 m diameter, for office buildings; one 1.5 m diameter, for apartment buildings, and one 0.6-0.9 m diameter, for individual users.

The Soviet Gorizont system will be replaced beginning in 1993 by eleven Express spacecraft. Each of the 2,500-kg satellites will carry ten 15W C-band and two 60W Ku-band transponders. Total power per satellite is 2.4 kW

In September Russia's Astra signed an agreement with Italy's Telespazio to create Astelit, a joint venture using Soviet Raduga geostationary military communications satellites with Italcable's network to provide international telephone and videoconferencing services to Western businesses working in the Soviet nations. Agreements were also signed by Telespazio with the Soviet firm Planeta and the government agency Agroresources to market remote-sensing data from Soviet spacecraft and introduce Italian computer technology into Soviet data-processing.

(e) Other Regions

The two satellites comprising Canada's fifth-generation Anik E series were launched aboard Ariane 44P rockets this year, Anik E-2 on 4 April and Anik E-1 on 26 September. The two 2,900-kg satellites carry a total of 24 12W C-band transponders plus 6 spares and 16 50W Ku-band transponders plus two spares. They are expected to serve Canada's needs until beyond the turn of the century. E2 suffered an antenna deployment problem on 12 April, but it was successfully deployed on 3 July by herculean efforts on the part of the Anik ground-control team. It went into service on 1 September.

On 19 March Mexico selected Hughes Space and Communications Group to build two Solidaridad satellites. The 1600-kg spacecraft will use the Hughes HS-601 bus and will be equipped with an L-band transponder for mobile communications capability as well as 18 C-band and 16 Ku-band fixed-service transponders. Arianespace was selected on 19 July to launch the satellites in 1994.

Israel's first commercial domestic satellite program, AMOS, was announced in March to be a two-satellite system with 12 Ku-band transponders for telephone, telex, facsimile, and television service, including direct broadcasting to 1-m receiving antennas. Israel Aircraft Industries will build the satellites, the first of which is planned for launch in 1994.

(f) International

In May an alliance to design, manufacture and market commercial satellites was formed by Deutsche Aerospace, France's Alcatel and Aerospatiale, Italy's Alenia, and Loral Space Systems of the U.S. The new consortium will coordinate bids on satellite contracts and share manufacturing activities..

The Soviet Union became the 121st member of Intelsat, and also signed a memo of understanding with Intelsat's board of governors to increase cooperation between Intelsat and Intersputnik aimed ultimately at merging the two international networks.

On 14 August an Ariane 44L booster launched the fourth (of five) satellites in the Intelsat 6 series. The 4,250-kg spacecraft carries 38 C-band and 10 Ku-band transponders for use in the high-traffic Atlantic Ocean region. In October Intelsat also announced, for the first time, access to its system on an experimental monthly basis for digital audio distribution services by all member nations.

In August Alpha Lyracom (formerly PanAmSat) signed agreements with Hughes Communications (U.S.) and the Great Wall Industry Corporation (China) to build and launch ORBX 1,2, and 3 aboard Long March rockets. The first launch is scheduled for early 1994. Great Wall will also buy services from Alpha Lyracom for domestic and Southeast Asia international communications. Alpha Lyracom's privately owned international constellation will offer a total of 72 C-band and 72 Ku-band transponders.

(2) Mobile Systems

Inmarsat-C portable-communicator service was initiated in the Pacific region on 4 January and in the eastern Atlantic area on 17 January. Inmarsat-C is a suitcase-sized unit that allows mobile users to communicate via the 9 Inmarsat satellites. The first commercial telephone call to use this service was placed by a passenger aboard a Singapore Airlines Boeing 747 on 25 September. Twelve ground stations installed this year will extend service to customers on a global basis. Besides communications, Inmarsat-C users will have access to tracking and position-location services via the U.S. Global Positioning System.

Two major U.S. truck fleets, one with 2,150 vehicles, the other with 370, began using Qualcomm messaging and position-location services employing mobile units called OmniTRACS in all their vehicles.

On 1 February Inmarsat contracted with GE AstroSpace in the U.S. to build 4 Inmarsat-3 satellites, which will be the first to incorporate navigation capability using the Global Positioning System. England's Marconi Space Systems is a subcontractor in the US$320-million procurement. The second Inmarsat-2 satellite was launched successfully by a U.S. Delta-2 on 8 March; it went into service over the Atlantic Ocean (at 15.5 degrees West longitude) on 13 April. On April 9th, Iceland became Inmarsat's 64th member, and will use the Inmarsat Hooksat project for dedicated communications among Iceland's fishing fleet.

ESA proposed development of Archimedes, a new system of

three satellites in Molniya orbits (elliptical orbits with high apogees, typically 40,000 km, and low perigees, around 600 km), for users in automobiles, planes, and trains. ESA's role would be to build, launch, and test one of the three satellites late in the 1990s; a commercial enterprise would then complete and operate the system. Launch into the required high-inclination orbit would be most efficient from the Soviet Baikonur Cosmodrome.

Canada's Telesat Mobile, Inc. contracted with Arianespace in June to launch its MSAT-1 satellite in 1994. The companion Mobile Satellite Corporation (U.S.) spacecraft is as yet uncommitted to a launch firm. Both satellites are being manufactured by a Hughes-Spar Aerospace team.

The Soviet Union announced a new mobile communications system called Marathon, to be operated commercially by a consortium of Soviet companies. It will use two different types of satellites: three Arkos geostationary-orbit spacecraft and two to four Mayak satellites in Molniya orbits for Arctic coverage.

(3) Navigation and Position Location

Operation Desert Storm demonstrated the extreme versatility and applicability of the U.S. Global Positioning System (GPS) to mobile surface units, including individual soldiers. Over 5,000 commercially built receivers were distributed and used to pinpoint locations in the trackless desert terrain. In July Japan's Sony Corporation began marketing 600-gram GPS receivers (including batteries) designated PYXIS IPS-360, priced at US$1,150, to recreational users such as boat owners, mountain climbers, ultralight and hang-glider pilots, etc. Commercial GPS receivers are also available from the U.S. firms Magellan Systems Corporation and Trimble Navigation.

A unique use of the GPS was highlighted by the establishment on 1 March of the Southern California Earthquake Center in the U.S., which will create a system to measure movements on the Earth's surface of less than 1 cm by continuous monitoring of the distance between many GPS receivers.

On 1 April a U.S. Northwest Airlines aircraft conducted the first flight test of a cooperative venture to combine use of the U.S. Global Positioning System (GPS - currently 15 satellites) and the Soviet Globol Orbiting Navigation Satellite System (GLONASS - currently 12 satellites). The purpose of the test was to demonstrate operation of both systems using the same radio signal. Both the U.S. and the Soviet Union have offered the use of their satellite navigation signals at no cost to all airlines.

In May the U.S. company Geostar, which had pioneered Radio Determination Satellite Service (RDSS) for position location, terminated operations and liquidated its assets to pay off

creditors. Former Geostar customers switched to Qualcomm, which currently has about 15,000 U.S. users. The French firm Locstar also terminated its operations in July because of inability to secure financing, leaving the estimated 50,000-unit European market to Eutelsat's RDSS division Euteltracs, which uses Qualcomm equipment, and to the Inmarsat-C service (see above).

B. Earth Observations

All three commercial remote-sensing organizations demonstrated the value of their technology during Operation Desert Storm in Kuwait and Iraq. Images offered by Eosat (U.S.), Spotimage (France), and Soyuzkarta (Soviet) often provided the only available data in the region for both military and non-military purposes. The high resolution of the Soviet KFA-1000 camera (sometimes as good as 3-m) was particularly noteworthy, although the need to retrieve the entire camera before making data available impeded somewhat its timely dissemination.

In August the U.S. Earth Observing System (EOS), to be launched late in the decade, was recast by dividing its six major multi-instrument platforms into 18 medium-sized satellites, each carrying about a third of the instruments planned for the original large 13,300-kg platforms. The smaller spacecraft, which would be comparable in scale to the Upper Atmosphere Research Satellite (see below), can be launched by Atlas 2AS boosters from the Western Test Range (see above) instead of having to use large Titan-4 vehicles. The small Earth Probes spacecraft originally planned to be part of EOS remain an essential part of the recast program, but pressure has also been exerted to redesign the EOS Data and Information System (EOSDIS) to accommodate new systems approaches and technologies.

The 6,800-kg U.S. Upper Atmosphere Research Satellite (UARS), often called the first step in "Mission to Planet Earth," was launched by Space Shuttle Discovery on 12 September. Its 10 instruments will provide detailed data on chemical processes in the upper atmosphere from 15 to 120 km altitude, focusing particularly on anthropogenic effects. UARS is the first spacecraft equipped to determine the interaction of the atmosphere's chemical reactions with winds and solar radiation. The spacecraft was built by GE AstroSpace, but scientists, engineers, and contractors from Canada, France, Germany, Italy, and the UK are major participants in its design, construction, and use. About a hundred scientists will also conduct ground and aircraft-based atmospheric measurements to complement the spacecraft's observations.

China launched a Weaver Girl 3 sounding rocket on 22 January to measure atmospheric data at 120-km altitude. The data are for use in designing space launchers and other space vehicles.

Data from the Total Ozone Mapping Spectrometer (TOMS) on the U.S. Nimbus-7 satellite recorded the second largest and longest-

lasting Antarctic ozone hole in history, ending in late December 1990. A new TOMS instrument was launched from the Plesetsk Cosmodrome aboard a Soviet Meteor-3 spacecraft in August 1991 to continue and expand stratospheric ozone data collection, shortly following the signing by Presidents Bush and Gorbachev of a far-reaching agreement on cooperation in environmental monitoring from space. It was the first U.S. science instrument to fly aboard a Soviet unmanned satellite.

Concerns about stratospheric ozone depletion have stimulated several advanced-technology options for replenishing the ozone, including an ozone generator deployed by a tether from a spacecraft down into the ionosphere, an orbiting chemical system to react with chlorine atoms (which destroy ozone), chlorine neutralization or ozone generation by lasers, and conversion of neutral chlorine molecules to negative ions by microwave or charged-particle beams

On 27 February the U.S. and Canada signed an agreement to cooperate in the launch, operation, and use of Canada's Radarsat, planned to begin mapping the Earth's polar regions in 1994. The spacecraft is being built by Canada's Spar Aerospace. In April Italy's Telespazio and the Soviet agency Agroresources agreed to work jointly on agricultural remote-sensing programs, supplementing Telespazio's prior agreement for remote-sensing development with the Soviet Planeta agency. On 10 April, Hungary and ESA signed an agreement to exchange information on space-based environmental monitoring, as well as on telecommunications and space science.

Four Canadian companies, MacDonald Dettwiler, Bristol Aerospace, Intera Technologies, and SED Systems, completed in August a definition study of a remote-sensing satellite series designated Keysat. The first Keysat spacecraft, GreenSpace, will focus on vegetation and water-related targets. No firm launch schedule has been established.

Japan's Earth Resources Satellite Data Analysis Center initiated a major program to map the Earth's geologic features, including mineral deposits, using the ERS-1 satellite scheduled for launch in February 1992 aboard an H-1 rocket. The Center has begun development of the computer software needed to create a global geological map by 1997. ERS-1 will be Japan's entry into the commercial remote-sensing market; it will be equipped with synthetic-aperture radar for all-weather imagery. ERS-1 will be followed in 1995 by the 3,000-kg Advanced Earth Observing Satellite, to be launched by an H-2, which will carry one French and two NASA sensors. A third satellite, which is expected to complement the U.S. Earth Observing System, is expected to be launched on an H-2 in 1998 or 1999.

ESA's Meteosat Operational Program (MOP-2) satellite was launched by an Ariane 44LP on 2 March, along with Luxembourg's Astra 1B. It is the second of three in the series. In cooperation with the European Community, ESA has set up three major programs

for obtaining environmental data through Earth observations. One of these, called TREES, focuses on assessing global forest damage; the second, named European Airborne Remote Sensing Capabilities, will develop all-weather airborne radar to complement and validate radar data from the ERS-1 and ERS-2 satellites (see below); the third is the Ocean Color Environmental Archive Network, which will analyze ocean plankton content and algae blooms.

In September Eumetsat agreed to lend the U.S. a spare ESA Meteosat-3 spacecraft until the U.S. Geostationary Operational Environmental Satellite (GOES-Next) can be readied for launch. GOES-Next has been delayed for a year (launch is now expected no sooner than 1993) due to development problems with its advanced sensor equipment, and the present GOES-7 is expected to cease operating late in 1992. Meteosat-3 will be moved further west (it was used in late August to monitor Hurricane Bob's movement up the U.S. east coast), so its current operation by Eumetsat's Darmstadt, Germany, control center will be supplemented by a new U.S. ground station at Wallops Island, Virginia.

On 31 March the Soviet Union launched Almaz, the first commercial radar satellite, aboard a Proton rocket. Its data supplement those available from the U.S. Landsat and the French Spot in that its radar can penetrate clouds, measure soil moisture and surface roughness, and map underwater terrain to 15-m resolution. The USSR also launched a new Resurs-F satellite on 21 May, carrying an MK-4 camera whose images, recovered with the camera in July, were marketed commercially.

In April Brazil requested bids to launch its small 115-kg environmental data relay spacecraft (Satellite de Coleta de Dados 1, or SCD-1) from Alcantara, a new launch site under construction at 2 degrees south latitude. Competitors are the U.S. Pegasus, the U.S. Scout, the Soviet Vysota, and a small Chinese rocket.

The U.S. NOAA-12 satellite, launched 14 May aboard an Atlas-E, joined two previous NOAA spacecraft in using its Advanced Very High Resolution Radiometer (AVHRR) to measure and monitor the severe drought conditions in sub-Saharan Sudan, where there are no ground-based weather stations. NOAA-12 is now making similar measurements in Southeast Asia. The data are useful in predicting agricultural yields.

ESA's ERS-1 environmental satellite was launched into its 800-km polar orbit by Arianespace on 16 July. Its radar altimeter and synthetic aperture radar, both operating superbly to date, extend environmental remote-sensing capability substantially over that of existing systems. Its orbit is being determined with unprecedented precision by a Dutch mobile laser ranging system and stationary Eurpean lasers, and ERS-1 will test for the first time a microwave ranging system consisting of the space-based Precise Range and Range Rate Equipmet (PRARE) and a global network of 30 automated ground stations. ERS-2, to be launched in late 1994, will include a Global Ozone Monitoring Experiment.

India's second remote-sensing satellite, the 980-kg IRS-1B, was launched into its 904-km polar orbit on 29 August by a Soviet Vostok from Baikonur Cosmodrome. Two linear imaging self-scanning cameras collect Earth data in the blue, green, red, and infrared spectral bands with 36 and 72-m resolution. Unlike its predecessor, IRS-1A, which transmits only to ground stations in India, data from IRS-1B will be made available on a commercial basis to ground stations in other countries. IRS-1A and 1B provide vital services in agriculture, land and water resources, forestry, wasteland delineation, ocean development, soil monitoring, and drought and flood management.

C. Small Satellites

The U.S. firms Motorola and Lockheed signed an agreement in March that designates Lockheed as the bus developer for the 77-spacecraft Iridium constellation for global cellular-telephone service, with Motorola responsible for the communications payload. The L-band Main Mission Antenna system was assigned on 31 July to the Raytheon Corporation. The satellites will be deployed at an altitude of 760 km in seven orbital planes. Several U.S. competitors to Iridium have since filed requests for licenses from the U.S. Federal Communications Commission: Ellipsat (an 18-satellite constellation of small, 180-kg L-band spacecraft in three orbits); Constellation Communications' Aries system (48 125-kg satellites in four 1,000-km orbits); Loral Qualcomm Satellite Services' Globalstar (also 48 small satellites); and TRW's 12-satellite constellation of 1150-kg spacecraft. Hughes Aircraft also proposed, but did not file for, a system called Tritium, consisting of three 1600-kg satellites orbiting 120 degrees apart. The U.S. Federal Communications Commission (FCC) on 26 September allocated specific spectrum ranges to low-Earth-orbit satellite constellations and recommended that the 1992 World Administrative Radio Conference (WARC-92) approve international spectrum allocations for this use.

On 26 March the international Consortium of Small Satellite Constructors and Service Providers, headquartered in Moscow, announced a plan to launch 24 to 36 small (70-kg) satellites to 1600 km orbits in four orbital planes. The Gonets satellites, employing well-proven Soviet military spacecraft technology, will be launched by Soviet Cyclone rockets, and will provide electronic mail, voice mail, facsimile, position location, and telemetry services. The Soviets are also planning a system called Coscon, to be developed by NPO Polyot. It consists of 32 600-kg satellites in four 1,000-km orbital planes at 83 degrees inclination. Coscon, too, is based on a current satellite type: the Informator 1 data-collection spacecraft launched on 29 January.

On 3 July Ball Aerospace (US) flew its prototype Quickstar small satellite bus as a secondary payload on a U.S. Delta

launcher. The bus is being offered to customers with 20-25 kg payloads. It has a volume of about 0.05 cubic meter, a gallium arsenide power panel with an area of about 1.1 square meters, can store about 0.5 gigabits of information, and can remain in orbit 3 months to a year. The prototype cost US$2.5 million, including launch.

The U.S. Pegasus, built by Orbital Sciences Corporation, launched 7 "Microsats" into a lower-than-planned orbit on 17 July. The 22-kg spacecraft, designed to evaluate for the Defense Advanced Research Projects Agency (DARPA) the usefulness of small ultra-high-frequency communications satellites to tactical military commanders in the field, are in 350-450-km orbits instead of the planned 715-km orbit, so they will last only about one year instead of three, and will not be able to provide continuous coverage as planned.

On 16 July Arianespace launched four small satellites as an auxiliary payload aboard the Ariane 4 that launched Europe's ERS-1 (see above). One was a 50-kg research satellite, UoSat-5, built by Surrey Satellite Technology of the British University of Surrey to photograph the Earth (it took excellent pictures of the burning Kuwait oil fields), to study the effects of radiation on semiconductors and gallium arsenide solar cells, and to serve as an orbiting relay for HealthNet, used by developing-nation hospitals and disaster relief operations. The 22-35-kg SARA and TUBSAT spacecraft were built by students at the French Ecole Superieure d'Ingenieurs en Electronique and at the Technical University of Berlin, respectively. SARA monitors radioemissions from Jupiter, to complement data from Ulysses and Galileo, and TUBSAT tests communication systems for remote expeditions. The fourth smallsat, 16-kg Orbcomm-X, was built by Orbital Sciences Corporation's Orbcomm division to evaluate the practicality of a commercial 20-satellite data transmission network. Contact with Orbcomm-X was lost on 22 July.

A student team from South Africa's University of Stellenbosch announced plans to develop and fly a small satellite called Sunsat. It would weigh about 50 kg, develop about 100W from its solar panels, and use three-axis attitude control. It would be placed in a Sun-synchronous 800-km orbit, and could be ready for launch as an auxiliary Ariane payload in 1994. Possible payload options include a ranging system for position location, stereo Earth observations, amateur-radio voice and digital communications, and communications with the ground control center at Stellenbosch. The concept is patterned after the University of Surrey's UoSat program.

IV. MANNED EARTH ORBITAL ACTIVITIES

A. Space Stations

(1) The Soviet Mir

The space station has been successful in maintaining its pointing accuracy of about 1 arc minute, using an attitude control system based on a magnetically suspended controlled momentum wheel (Gyrodyne) with a maximum angular momentum of 1000 N-m-seconds.

A Japanese journalist, Toyohiro Akiyama, spent eight days aboard Mir from 2 to 10 December, 1990. The first journalist in space, Akiyama is news director of the Tokyo Broadcasting System (TBS). He joined Soviet cosmonauts Musa Manarov and Viktor Afanasyev in conducting medical and biological experiments and made daily live broadcasts on his experiences to TBS television viewers. TBS paid US$12 million for Akiyama's training and flight.

Two French astronauts, Michel Tognini and Jean-Pierre Haignere, began training at the Soviet Union's Star City on 8 January for an 8-day mission in summer 1992 designated "Antares." The French space agency CNES will pay US$12 million for the training and for the flight of one French astronaut on the mission. Two German astronauts, Klaus Dietrich Flade and Reinhold Ewald, have been at Star City since mid-1990, training for a 12-day Mir mission also planned for 1992 and costing about US$14.2 million.

On 25 April Soviet cosmonauts Viktor Afanasyev and Musa Manarov went outside Mir to conduct experiments on space construction techniques and to inspect a malfunctioning antenna that had caused docking problems during a Progress resupply mission on 26 March. The follow-on team of Mir cosmonauts, Anatoly Artsebarsky and Sergei Krikalev, repaired Kvant-1's docking module and installed a U.S.-Soviet cosmic-ray instrument during spacewalks on 25 and 29 June. They subsequently erected a 14-m tower called Sofora on the Kvant 1 module during spacewalks on 15, 19, 23, and 27 July. Sofora was assembled from 20 prefabricated girders using titanium-nickel "shrink" fasteners designed specifically for in-space assemblies. Besides its value as a space construction experiment, Sofora will also be used as a thruster mount to provide more effective attitude control for Mir.

A British research chemist, Helen Sharman, joined Soviet cosmonauts Anatoli Artsebarsky and Sergei Krikalev aboard Mir to conduct about 20 experiments during an 8-day mission called "Juno," launched on 18 May. An Austrian, Franz Viehboeck, was launched to Mir aboard Soyuz TM-13 on 2 October, along with Russian cosmonaut Alexander Volkov and the first Kazakhstan cosmonaut, Toktar Aubakirov. The Austrian and the Kazakh returned to Earth on 10 October with Artsebarsky, who had been aboard Mir since May.

The Soviet union announced in April that plans for Mir 2 had been scaled back from the original four-module, 100,000-kg configuration. Mir 2 will now consist of a new central module, with Mir-1's existing modules attached to it.

(2) Space Station Freedom

Budget concerns in the U.S. and Europe resulted in a scaleback of Freedom's capabilities and schedule. Current plans call for "human-tended" capability early in 1997, with a single, shortened U.S.-built laboratory module holding eight (instead of 20) experiment racks, Canada's Mobile Service Center, and 18.75 kW of power (10 kW available to users) instead of 75 kW. The Shuttle will provide life support for up to 13 days at a time. Permanently manned capability will not occur before 2000, when the full 75 kW will be available along with a shortened habitability module that accommodates 4 instead of 8 crew members, the European pressurized Columbus laboratory module, and the Japanese Experiment Module.

On 3 May Italy announced selection of five astronaut candidates for the Freedom-Hermes-Columbus program: Maurizio Cheli, Franco Ongaro, Stefano Santonico, Roberto Tacchino, and Luca Urbani.

B. The Space Shuttle

The U.S. Space Shuttle fleet flew 7 missions in 1991. 8 are planned for 1992, when the fourth orbiter, Endeavour, will join the fleet (see below).

The Astro science payload of one X-ray and three ultraviolet telescopes returned to Earth a day early, on 11 December 1990, due to weather constraints after a 9-day flight. Although problems with the automatic pointing-system software and the onboard data display units for all the ultraviolet telescopes limited their data collection to 140 of the 250 planned targets, scientists were elated with the quality and quantity of data, which included the discovery of hundreds of hot, energetic young stars in the Magellanic Cloud galaxy and the finding of violent stellar winds surrounding the large Wolf-Rayet class of stars. Indeed, Astro was so successful that earlier plans to terminate the program were revised, and a second Astro flight is now planned for 1993.

On 8 April Shuttle astronauts Jerry Ross and Jay Apt successfully released a jammed antenna on the Gamma Ray Observatory, which made its successful launch possible (see below). On a subsequent spacewalk the following day they also conducted tests of personnel carts and construction methods for space station Freedom.

The new Shuttle Orbiter Endeavour, which will replace the Challenger Orbiter lost in January 1986, was rolled out of the Rockwell International plant in Palmdale, California on 25 April. Endeavor was delivered by Rockwell to NASA on time and US$40 million below its budgeted cost. Endeavour's first mission, in

April 1992, will be to rescue the 4,000-kg Intelsat 6-F3 satellite stranded in orbit by its Titan booster in March 1990.

C. Other Manned Orbital Programs

Presidents Bush and Gorbachev signed an agreement in Moscow on 31 July to fly Soviet cosmonauts on Shuttle flights and American astronauts on Mir. The first missions could be conducted as early as 1992.

Salyut 7, the present Soviet Mir's predecessor, reentered the atmosphere and broke up over Argentina on 7 February. Deorbiting of the abandoned 40,000-kg space station occurred prematurely due to a fourfold increase in atmospheric density generated by unusually high solar flare activity. Salyut 7 was launched in 1982 and last inhabited by cosmonauts in 1986. The debris which reached Earth fell in unpopulated areas and caused no injuries or damage.

The European Space Agency (ESA) initiated a study by three companies, Aerospatiale of France, British Aerospace, and Belgium's Space Applications Services, to evaluate an automated logistics vehicle, Love, that would carry payloads from launchers such as Ariane 5 to space stations subsequent to Freedom.

All major test objectives were completed in June, a month ahead of schedule, on the joint Italian-U.S. Tethered Satellite System (TSS) program scheduled for launch on U.S. Shuttle Atlantis in August 1992. The satellite was built by Aeritalia, now merged with Selenia to form Alenia Spazio as of 1 March; the 20-km deploying system was built by Martin Marietta. Goals of the experiment with the 520-kg, 1.6-m-diameter satellite are to demonstrate the feasibility of placing tethered payloads into orbit, demonstrating maneuverability, and conducting electrodynamic studies of the Earth's ionosphere and magnetic field.

The ESA Hermes program to develop a manned spaceplane carried by Ariane 5 was reprogrammed this year to reduce the number of vehicles built this decade from two to one and to reduce its initial flight rate from twice to once annually. The spaceplane (at 48,800 kg) is also currently overweight by about 2,000 kg, a concern that will be resolved by design improvements or by cutting its payload and increasing Ariane-5's capability.

D. Life Sciences Research

The U.S. Spacelab Life Sciences flight 5-14 June aboard Space Shuttle Columbia focused on precise measurements of the astronauts' hearts, vestibular systems, metabolism, and hormone levels. Medical specialists James Bagian, Drew Gaffney, Millie Hughes-Fulford, and Rhea Seddon also tested systems for medical operations on Space Station Freedom. One surprising result of the

research was that physiological changes due to weightlessness occurred very quickly, as indicated by shifts in blood volume from the legs to the upper torso, increased heart rate, reduced liquid and food consumption, weight loss, reduction in total plasma volume, and motion sickness. Test results also suggested a revision in lung function theory and a prospect that sensory conflict in the brain, which causes motion sickness, may be able to be resolved.

V. SPACE EXPLORATION

A. Unmanned Systems

NASA's Galileo spacecraft received a gravity-assist boost from Earth in December 1990, dipping down to 952 km over the Southern Hemisphere. During the encounter Galileo's instruments were tested by taking infrared and visual images of Antarctica and Australia, making measurements of atmospheric constituents, and photographing the far side of the Moon. A second gravity-assist from Earth is scheduled for December 1992. Efforts to deploy the spacecraft's jammed main communications antenna by thermally shrinking it with a "cold soak" were unsuccessful, and more strenuous efforts such as shaking, rattling, or colder "soaks" will be attempted after Galileo's forthcoming encounter with the asteroid Gaspra (see below). One possible cause of the problem was the extra round trip on the ground that the spacecraft underwent between JPL in California and the Kennedy Space Center in Florida due to the Shuttle Challenger's failure in 1986, which may have rubbed off the lubricant on the pins that held the antenna in its closed position. Without the 134,000 bps transmission capability of the unfurled antenna, Galileo's low-gain antenna's 10 bps transmission rate will preclude most data reception from the Jupiter orbiter, but would allow data to be received from the Jupiter atmosphere probes.

Germany signed an agreement with the Soviet Union on 16 January to provide two cameras and a gigabit computer memory for the Soviet Mars 94 mission. The Soviet Union has reprogrammed the mission to postpone until 1996 the second Phobos vehicle flight, which will carry a rover and balloons designed by French and U.S. engineers to explore the Martian surface. In tests of the balloons conducted in September from the Norwegian Andoya Range, one of the three ballons launched operated as planned; the other two did not reach the necessary altitude.

The U.S. Magellan spacecraft completed its first radar mapping cycle of Venus in May, covering about 84% of the surface. A random computer failure in March was quickly corrected by ground controllers, but excessive solar heating of the spacecraft required occasional use of the antenna as a Sun shield, reducing slightly the time available for mapping. In general, the spacecraft performed magnificently, providing data of unprecedented quality on folded rock formations, past volcanic

activity, and unusual crater features. Observations made in August suggest that Venus may still be geologically alive, because images made at different times appear to show changes that could be due to a Venusquake and its resulting landslides.

The U.S. Gamma Ray Observatory (GRO), the second of the four Great Observatories, was launched aboard Space Shuttle Atlantis on 5 April. The 16,000-kg GRO, the heaviest civil payload ever carried into space by the Shuttle, carries four independent instruments to measure such phenomena as intense gamma-ray bursts and the heavy-particle radiation produced by supernovas and black holes. The spacecraft was built by TRW Space and Technology Group under contract to NASA. Initial experiments for the spacecraft's four instruments focused on observations of the Crab nebula, a binary black-hole candidate star named Cygnus X-1, gamma-ray bursts, several pulsars, and intense solar-flare activity. In June GRO's Energetic Gamma Ray Experiment Telescope (EGRET) detected the most distant and by far the most powerful gamma-ray source ever seen: 7 billion light-years distant with an energy 10 million times that of our own Milky Way galaxy. GRO also sparked a major reexamination of the theory behind cosmic-ray bursts when the first four months of data from its Burst and Transient Source Experiment (BATSE) revealed 117 bursts randomly distributed in all directions and distances rather than the neutron-star bursts limited to the Milky Way galaxy that had been observed previously.

In April NASA announced that the troubled Hubble telescope was capturing nine out of ten of its science targets, after software partly correcting the jitter due to solar heating effects on its power arrays had been emplaced in the spacecraft's computers. Plans for a 1993 Shuttle repair mission, long scheduled as part of the original Hubble Telescope program to replace the wide-field camera, now call for replacing the solar panels, installing a Corrective Optics Space Telescope Axial Replacement (COSTAR) to correct the spherical aberration caused by improper grinding of the primary mirror, and replacing the spacecraft's gyroscopes, two of which have failed.

Among Hubble's discoveries this year were detection of planetlike masses of ionized iron circling the star Beta Pictoris, large intergalactic clouds of hydrogen, a unique jet of material issuing from the large unstable star Eta Carinae, a high concentration of young "blue straggler" stars in the cluster 47 Tucanae that appear to result from collisions of old red giants, the ring left by the exploded star Supernova 1987A, and accurate measurement of the distance to the Large Magellanic Cloud.

On 18 April NASA's Lewis Research Center announced that the Solar and Heliospheric Observatory (SOHO) will be launched by a General Dynamics Atlas 2AS rocket in July 1995. SOHO is part of the International Solar and Terrestrial Physics program, a joint effort by ESA, Japan, and the U.S. It will study the factors that affect the solar corona and the interior solar structure from its

1.6-million-km orbit during a projected service life of 2 years.

On 2 July NASA announced plans for a new Discovery Program to rendezvous with and study several Earth-approaching asteroids. The first mission, Near Earth Asteroid Rendezvous (NEAR), could be launched aboard a Delta 2 as early as 1997. Possible targets include 1943 Anteros in July 1988, and 1982XB in November 1999.

In July ESA's Giotto spacecraft, which photographed the nucleus of Halley's Comet in 1986, was reactivated and sent to meet Comet Grigg Skjellerup in July 1992. Also in July the U.S. Galileo spacecraft, on its long ride to Jupiter, was guided toward the asteroid Gaspra, which it flew past on 29 October. Data from the encounter were stored, and will be transmitted over the high-gain antenna if it is subsequently deployed successfully. If not, the Gaspra data will be sent to Earth using Galileo's low-gain antenna during the spacecraft's second Earth gravity-assist in December 1992.

On 21 August the European Ulysses spacecraft passed behind the Sun relative to Earth, offering an excellent opportunity to study the corona using the radio interference caused by the conjunction. The spacecraft will make a close approach to Jupiter (375,000 km) in February 1992, using the gravity assist gained from the massive planet to swing it into a heliocentric polar orbit.

Significant advances were made this year in the technology required for detection of other planetary systems using radio, infrared, and optical astronomical methods. In addition to the abovementioned discovery of a pseudoplanet by the Hubble telescope, British radioastronomers at Jodrell Bank claimed to have discovered a planet orbiting a pulsar.

Supplementing ongoing U.S. programs in SETI, the Search for Extraterrestrial Intelligence (SERENDIP, Ohio State University, and Harvard University), new programs were begun this year at the Argentine Radio Observatory and by the University of Western Australia and CSIRO with the Parkes telescope. Soviet astronomers at Samarkand plan to conduct "magic frequency" searches at the positronium line, 203.385 GHz, and to initiate a search strategy which looks at stars when they are in opposition from the Sun using multichannel spectrum analyzers. Construction of instruments for NASA's Microwave Observing Project that can detect drifting and pulsed signals is nearing completion.

In August the U.S. and Argentina signed an agreement to to conduct joint research in Earth and space sciences. The first joint mission to be undertaken by NASA with a Latin-American country is the Satelite de Aplicaciones Cientificas-B (SAC-B), which will measure high-energy and hard X-ray emissions from solar flares and cosmic-ray burst sources. The Argentine National Commission on Space Activities will build the spacecraft, and Penn State University will build the X-ray cosmic background instrument.

B. Manned Systems

A major milestone in planning the U.S. Space Exploration Initiative was the release on 11 June of the study conducted for Vice-President Quayle by a special Synthesis Group, led by former U.S. astronaut Thomas Stafford. The study suggested four possible scenarios for a long-term program designed to establish and maintain bases on the Moon and Mars. Key technologies identified by the report were a heavy-lift launch vehicle (i.e., up to 140,000 kg to low Earth orbit) and the use of nuclear thermal propulsion to reduce trip time between Earth and Mars orbits. The Synthesis Group reviewed over 2500 ideas and concepts submitted in response to a nationwide solicitation, including 550 received and assessed by the American Institute of Aeronautics and Astronautics.

VI. TECHNOLOGY ADVANCEMENT

A. Propulsion

After a successful 350-second test in February, Japan experienced a series of difficulties in developing the 100,000-kg-thrust liquid-propellant LE-7 engine for its new H-2 launch vehicle, which may necessitate postponing the first H-2 launch until 1994. Successful tests of Nissan's H-2 solid-propellant booster, however, completed in May, marked a transition to production of the boosters.

The Solid Rocket Motor Upgrade for the U.S. Titan 4 exploded on its first test in April, due to a propellant design flaw. The motor's builder, Hercules, plans to test a proposed design modification in subscale tests on 1-m motors.

On 24 June the Soviet Union announced development of a new dual-fuel engine, RD-701, which first employs kerosene and then liquid hydrogen as fuels, with liquid oxygen as the oxidizer. Dual-fuel systems were actively researched by the U.S. in the 1970s but never flown.

On 28 August the scaled-down Advanced Solid Rocket Motor (ASRM) for the U.S. Space Shuttle was successfully tested for 30 seconds. This was the first of five scheduled tests on the 8-m motor; a second test of the 18,000-kg test motor (on 26 September) was also successful.

During 1991 India tested and qualified the 125-tonne solid-propellant booster for the Polar Satellite Launch Vehicle (PSLV), scheduled for first launch in 1992. The PSLV's second-stage propulsion system, a 37.5-tonne liquid-propellant engine employing unsymmetrical dimethyl hydrazine and nitrogen tetroxide propellants, was also tested successfully, as were the PSLV's third and fourth-stage motors. India has also tested a 1-tonne cryogenic engine, and is now building its successor, a 12-ton

hydrogen-oxygen engine to be used as the third stage of the PSLV, boosting its payload capability to 2,500 kg into geosynchronous transfer orbit.

B. Power

In January the Soviet Union sold a complete unfueled Topaz-2 nuclear space power reactor to the U.S. for evaluation and study, to aid U.S. agencies in developing future thermionic power conversion systems for use in nuclear space powerplants. The U.S. Space Exploration Initiative has rejuvenated U.S. interest in both nuclear thermal rockets and nuclear-electric propulsion, and a number of new study programs on these systems were initiated this year in the U.S.

1991 saw a resurgence of interest in power satellites. An international symposium, "Power from Space," held in Paris during August, concluded that energy and environmental requirements for the 21st century, combined with major technology advances in power beaming (lasers and millimeter or submillimeter microwaves), photovoltaics (multispectral cells with efficiencies up to 40%), low-cost launch vehicle concepts (electromagnetic and gas-gun launchers and both airbreathing and rocket-powered single-stage-to-orbit designs), and large-scale space structures called for reconsideration of the now-obsolete "reference designs" evaluated in the late 1970s. The symposium identified the use of lunar materials for orbiting power stations, constructing power stations on the Moon, and using lunar-surface helium-3 for Earth-based fusion powerplants as possible future options. Several power-beaming experiments using S-band microwaves (2.45 GHz) and lasers are being explored for the International Space Year.

C. Structures and Materials

A one-third-scale model of a large (10-m diameter) deployable antenna was built at Japan's Institute of Space and Astronautical Sciences. The antenna, which will be an element of the Very Long Baseline Interferometer scheduled for launch in 1995, consists of a flexible metallic mesh, a cable network which supports the mesh in a precise parabolic shape, and six radial masts which extend outward. This is the first space structure to use a pre-tensioned cable network. A partial full-scale model is to be completed by the end of 1991.

Japan also completed building the components of a 3.5-m deployable solid-surface antenna, to be used on ETS-VI which is scheduled for an H-2 launch in 1993. During launch the antenna's dish is stowed in three pieces, which are deployed into a single dish by springs when the spacecraft reaches orbit. Final assembly of the antenna will be accomplished by the end of the year.

During 1991 the U.S. National Aerospace Plane (NASP) program

developed several new lightweight and high-temperature materials. Composites using graphite, polymers, and ceramic fibers can reduce the structural weight of spacecraft by up to 50%, and titanium-matrix composites were demonstrated in August to retain their strength at temperatures over 700 Celsius. NASP-derived carbon-carbon composites, descended from those used on the U.S. and Soviet shuttles, are expected to survive much longer duration trajectories at temperatures exceeding 1700 Celsius.

D. Space Debris

An Orbital Debris Program was established in the U.S. this year by NASA and the Department of Defense to improve modeling, monitoring, and data processing of debris 0.1 to 10 cm diameter in low Earth orbits. Japan's National Aerospace Laboratory is also modeling debris structure and collision processes on its supercomputer.

The 68-month flight of NASA's Long Duration Exposure Facility (LDEF) resulted in detection of over 15,000 meteoroid impacts from both natural and human sources, 5,000 of which were larger than 0.5 mm. Measurements included beta meteoroids, which are accelerated by solar radiation, and debris impacts on LDEF's trailing edge, implying the existence of debris in elliptic orbits. Results from LDEF are already being incorporated into the design of Space Station Freedom by the U.S., Europe, Japan, and Canada.

Three spent rocket stages exploded between October 1990 and June 1991 -- one of them after 16 years in orbit -- releasing over 500 trackable pieces of debris into very long lifetime orbits and endangering, in particular, spacecraft in orbits between 1000 and 1700 km.

Ball Aerospace and Kaman Aerospace in the U.S. completed preliminary conceptual design of a Debris Collision Warning Sensor for possible use aboard space station Freedom. It is a 1-m optical telescope that would eventually be paired with a high-power radar detector for final tracking of debris spotted by the telescope. It could be ready for test in the U.S. Shuttle by 1995.

E. Microgravity Research Facilities

The French space agency CNES has proposed development of a recoverable capsule able to carry 900-kg payloads into low Earth orbit for up to 3 weeks. The capsule, called Cariane, would be launched as an auxiliary payload on Ariane 5, and separated at the same time as the vehicle's first stage.

NASA selected three contractors to provide the six services needed for its Commercial Experiment Transporter (COMET) program: Space Industries, Space Services, and Westinghouse. First launch

is scheduled for September 1992. Westinghouse also annouced availabilty of its Westar launch-and-retrieve experiment capsule service, scheduled for first launch in 1993. It can be used not only with the COMET launcher but also with other launch vehicles. The capsule carries up to 140 kg of payload and remains in orbit 30-100 days.

Novespace (France) completed microgravity experiments for ESA, CNES, and Japan's Ministry of International Trade and Industry aboard a French Defense Ministry Caravelle Zero G aircraft modified for microgravity research by CNES. The business volume generated by these test series allowed the firm to cut the price for a 3-day series, involving up to 120 parabolic flight maneuvers each providing about 25 seconds of microgravity for a 150-kg payload, to US$28,000.

On 8 May a Maxus sounding rocket launched from Sweden's Esrange facility in Kiruna reached only a quarter of its intended altitude (200 km vs 800 km, which would have provided 15 minutes of microgravity time). A joint effort of MBB (Germany) and the Swedish Space Corporation, Maxus is designed to carry 420 kg to 875 km. Its first payload was a group of ESA experiments on materials, biotechnology, and fluid mechanics.

The first flight of the U.S. Prospector sounding rocket, built by Orbital Science Corporation's Space Data Division for the Joust microgravity research program, failed on 18 June when it was destroyed after veering off course. It was the first failure of a Space Data rocket after 13 successful launches. Subsequent Space Data launches of two Zest rockets carrying military research payloads, were successful.

On 18 June Alenia Spazio (Italy), Deutsche Aerospace, and Matra Marconi Space (France) signed an agreement to operate ESA's 4,000-kg Eureca retrievable platform, scheduled for launch by the U.S. Shuttle in 1992. The agreement will take effect after the first flight. Eureca can remain in orbit for 6-9 months.

F. Microgravity Research

During the flight of U.S. Shuttle Atlantis from 2 to 11 August three different techniques were used to grow large, high-quality protein crystals in the Bimda commercial payload. Aldolase was grown by materials dispersion, and crystals of urokinase were grown both by osmotic dewatering and by liquid-to-liquid and gradient diffusion.

VII. EDUCATION

A. Experimental Activities

Three space experiments being coordinated by Students for Exploration and Development of Space (SEDS) involve international

student cooperation. Students at the University of Alabama are working with their counterparts at the Imperial College of Science and Technology in London on two Getaway Special experiments aboard the U.S. Shuttle in 1993. One experiment focuses on heat transfer in microgravity using a fluid phase separation material; the other on determining how foams form in space. The third experiment brings University of Alabama students together with students from the Cheng Kung University in Taiwan, to work on a tethered-satellite experiment to be launched as a secondary Delta payload in June 1993.

The small amateur radio-astronomy satellite SARA, designed and built by French students (see above), is now available to amateur astronomers worldwide.

Under the auspices of the Space Agency Forum for the International Space Year (SAFISY), the French space agency CNES is coordinating an international program of training in the use of satellite technology. Typical applications for developing countries include assessing deforestation, urban pressures on agricultural lands, environment in coastal zones, and geological risks such as active volcanoes and landslides. Participating countries include Colombia, Peru, Morocco, Algeria, Tunisia, Burkina Faso, and five Southeast Asia countries. The first training seminar was held in Bangkok in November; the second in Tunis in December.

B. Teaching Programs

The International Space University held its fourth summer session in Toulouse, France this year, postponing the originally scheduled Moscow summer session to 1993. 130 students from 30 nations attended the session, whose main design project was an international Mars mission. George van Reeth, retiring Director of Administration for ESA and a former IAF president, was selected to take office in January 1992 as the first president of the ISU. ISU's 1991 budget has grown to US$2 million, contributed by 125 sponsors.

The first International Space School was conducted for 14-18-year-old students at the University of Kent in the UK from 17 August through 7 September. 25 British students from Brunel University's Space School were invited by the Soviet space society Soyuz to a 12-day tour of Soviet space facilities in September, following a 10-day visit by four Soviet students to Brunel in August.

In August 1991 a group of teachers selected from 21 nations met at the International Space Camp, Huntsville, Alabama, USA to draft an International Space Education Initiative stressing the need to introduce space education into all aspects of the educational systems of all countries and to encourage more international cooperation and exchanges.

During 1991 U.S. space corporations committed large sums to support educational programs ranging from kindergarten through university graduate school. Hughes pledged US$15 million; Rockwell US$5 million, TRW US$4.5 million, Comsat US$1.1 million, and Martin Marietta US$3.1 million.

The first of four videoconferences for teachers run by NASA's Educational Affairs Division during this school year, held in October, focused on space exploration. About 2,000 teachers participated in the two-way discussion with NASA Office of Exploration officials.

The U.S. National Science Foundation is developing materials for cross-teaching many different science and mathematics disciplines based on the concepts involved in the Search for Extraterrestrial Intelligence (SETI). As part of the International Space Year (ISY) these materials will be translated into the languages of interested countries.

Educational videotapes on space science have been produced in Japanese and English by Japan's Institute of Space and Astronautical Sciences (ISAS) for distribution to schools and other public education institutions in Japan and elsewhere in Asia.

The Education Department of the French space agency CNES has developed a new curriculum on Earth observation and remote sensing using kite photography and image processing on personal computers. The curriculum will be presented to educators during a July 1992 international seminar to be held in France as part of the International Space Year.

C. Public Awareness

The Euro Space Center's Space Camp opened on 19 June in Redu, Belgium. Aimed at educating young people in space technology and encouraging them to pursue careers in space, the camp is organized into three age levels for 10 to 18-year-olds to study space science, build and launch small rockets, and experience astronaut training and flight via a simulator.

The global contest for a paper on the subject "Together to Mars," organized by the Planetary Society, has drawn papers from 30 countries. The 20 finalists will attend the World Space Congress in August 1992. A Japanese contest on the theme "The Future of Space for You" elicited 250 papers from high schools all over Japan. The winners will also attend the World Space Congress.

VIII. SPACE LAW

International bodies concerned with space science and space law are paying increasing attention to the subject of space debris. The American Institute of Aeronautics and Astronautics' completed a special study in 1991 called Orbital Debris Mitigation Techniques: Technical, Economic and Legal Aspects. In addition to the economic and technical aspects, the study describes the existing regulatory framework and addresses several options for implementing those techniques, both nationally and internationally. In addition, the United Nations General Assembly called for Member States to consider the issue of space debris and suggested that it could become an agenda item within the Committee on Peaceful Uses of Outer Space in the future.

During the 34th session of the International Institute of Space Law, current space law cases and problems were addressed, including definitions of terms, legal aspects of settlements on the Moon and Mars, and legal implications of nuclear powered satellites. Other topics were also discussed, including proposals for a new space treaty, space law and feminist jurisprudence, commercial uses of space resources, risk allocation and liability, and the development of a convention for space debris.

The SETI Committee of the International Academy of Astronautics elaborated a "Declaration of Principles for Activities following the Detection of Extraterrestrial Intelligence." The declaration was approved this year by the Academy, the International Institute of Space Law, COSPAR, Commission J of URSI, and the International Astronomical Union. The document establishes guidelines for SETI observers and institutions to use in verifying signals and disseminating information on their discovery.